Review of the pattern language for innovation diffusion in urban systems: the city as a living code

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Abstract
This article incorporates a review by Prof. Dr. Schachtner of Dr. Steffen Braun's dissertation as a scientific article and its appreciation in the context of the German Smart City movement. **Objectives** The review analyzes Braun's dissertation, which develops a model language for the diffusion of innovation in urban systems. The aim is to understand cities as complex, multi-layered innovation systems and to enable adaptive strategies for sustainable transformations. This is crucial because urban innovations must be coordinated in an interdisciplinary and long-term manner in order to achieve climate neutrality and resilience. **Prior work** The work builds on concepts such as Christopher Alexander's Pattern Language from architecture and software development, supplemented by transition research (e.g. Geels) and KDD methods (Kriegel/Schubert). It combines urban innovation research with systems theory approaches to open ecosystems and expands the concept of innovation beyond technical hypes. Braun combines qualitative and quantitative knowledge discovery methods (KDD) to extract patterns from large empirical datasets. Data comes from diverse urban contexts and time periods, taking into account systemic inertia and global dynamics – a robust pipeline for generalizable insights. **Results** Key results are a universal pattern language that models cities as networked systems, defines innovation as a cooperative process, and provides patterns for communication and scaling. The analysis empirically validates recurring patterns and emphasizes complexity management. For scientists and researchers, it provides a framework for interdisciplinary studies; Practitioners in administration, business and politics receive controllable instruments for transformations. It promotes cooperation and evidence-based planning in heterogeneous cities. **Value** The unique contribution is the technology-independent, formalized model language as a bridge between theory and practice – methodologically sound, empirically robust and new in urban research. It sets standards for resilient urban development and inspires follow-up research with case studies.

Keywords: Sample Language Innovation Diffusion, Urban Systems, Transformation to Climate Neutrality, Open Ecosystems

1. Review
Steffen Braun's dissertation "Model Language for Innovation Diffusion in Urban Systems" represents a substantial analysis and conceptual development of urban innovation research, focusing on the sustainable and technological transformation of cities. Based on the thesis that cities are to be understood as multi-layered, complex innovation systems, the thesis develops a universal pattern language that systematically captures and structures innovation processes and thus makes them usable in terms of communication and control technology. The aim of the thesis is to offer different groups of actors – from science and administration to business and politics – a common set of instruments that allows an integrative view of complex urban innovation dynamics.

Among the central starting points of the dissertation is the combination of quantitative and qualitative methods of knowledge discovery in databases (KDD) in order to identify

empirically based, generalizable patterns. This methodology makes it possible to analyze large amounts of data on urban innovations and to derive valid recommendations for action from them. The extensive selection of empirical data collected across different urban contexts and time periods provides a robust pool for modelling innovation diffusion in urban systems. Importantly, the work takes into account the long-term time dimensions, global developments, and the systemic inertia of urban transformation processes – aspects that are often neglected in typical innovation studies.

An analysis of central findings from the thesis provides the opportunity for the following evaluation and classification:

First, the thesis understands cities not as monotonous entities, but as open, multi-layered innovation systems that operate in different spatial and functional levels and have different characteristics. This system-theoretical perspective is particularly suitable for capturing the multitude of levels of actors and actions that are relevant for urban innovation. Such systems are characterized by a high degree of interconnectedness, different dynamics and the integration of technical, social and organizational elements. This complexity is seen as a challenge and at the same time as an opportunity for innovative transformations.

Secondly, the thesis is based on an integrative, expanded concept of innovation, which encompasses technical, social and organizational innovations equally and emphasizes their long-lasting development processes as well as mutual dependencies. Thus, innovation is not reduced to individual technologies, but seen as a cooperative, evolutionary process within urban ecosystems. This comprehensive concept of innovation is particularly suitable for capturing the many facets of urban developments, from smart infrastructure to social innovation.

Thirdly, the dissertation emphasizes the importance of a pattern language as a tool for managing complexity, as it has established itself in the discipline of software development. The ability to systematically communicate experience and best practice in the form of standardised patterns is essential to promote interdisciplinary and cross-sectoral cooperation. The pattern language is seen as a bridge that brings together theoretical knowledge and practical application orientation. It also enables the scaling and adaptation of innovation solutions in different urban contexts.

Beyond hype cycles, the work shows a deep anchoring in current research discourses on digitally controlled urban development and the urban transformation towards climate-neutral cities in the 21st century. This sharpens the focus on theoretical foundations and proven empirical methods that provide a stable framework for innovation pattern formation. Such structural depth and systemic breadth are a relevant contribution, especially for large, heterogeneous urban systems and their digital transformation processes.

The dissertation benefits from clear methodology, systematic theoretical integration and a broad empirical fund; nevertheless, the practical feasibility of the developed pattern language is partly conceptual. The work could gain further impact through additional case

studies or concrete implementation examples in various urban innovation fields and, above all, retain long-term relevance in the continuation of further constructive work. A further component of this follow-up research could also be increasingly dedicated to further differentiation from related innovation models in order to further strengthen the specific innovation performance among the numerous concepts of urban transformation.

Overall, Steffen Braun's work is a significant contribution to the interdisciplinary and generalist understanding of urban innovation diffusion, which combines methodologically sound recommendations for planning, control and science regardless of technology. Through its system-oriented perspective and use of a formal model language, it sets new accents in urban innovation research and thus sets standards for future transformative design projects in urban development. It is important to note that the work highlights the benefits of evidence-based pattern languages as tools to reduce complexity and improve communication between different urban actors in an interdisciplinary manner. The dissertation is methodologically robust, theoretically sound and therefore opens up further research on practical application in a special way via additional case studies on the implementation and impact of the topic. Overall, Braun's research advances the theory of urban innovation adaptation and diffusion and offers valuable insights for sustainable and resilient urban development, which forms a solid basis for future empirical and applied urban innovation work.

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2. Supplementary Scientific Proposal for Complementary Topics

Following the present review of Steffen Braun's dissertation, several supplementary topics can be identified, which will be dealt with in depth by scholars. The dissertation develops cities as complex, open innovation systems and shows that innovation diffusion in urban contexts cannot be understood as a linear transfer of individual solutions, but as a multi-layered, cooperative and long-term transformation process (Braun, 2024; Geels, 2005). It is precisely this strength of the work that results in a need for further scientific clarification, because the theoretical breadth of the approach opens up numerous possibilities for connection to innovation, governance and transformation research (Schachtner, 2022).

A first complementary topic area concerns the more precise theoretical specification of the concept of innovation. The review highlights that Braun uses an expanded concept of innovation that takes into account technical, social, and organizational innovations equally (Braun, 2024). This conceptual breadth is particularly viable for urban systems because cities encompass not only technical infrastructures, but also social practices, administrative routines, and political negotiation processes. For a scientific supplement, however, it would be necessary to discuss how this broad concept of innovation differs from narrower, technologically or market-centered understandings of innovation. In transformation

research, it is emphasized that system innovations are to be understood as co-evolutionary processes between technology, institutions, markets, actor constellations and cultural models (Geels, 2005). Such an explicit theoretical connection would further strengthen the conceptual viability of the dissertation and at the same time increase its compatibility with international innovation debates.

A second topic area concerns the more detailed analysis of urban diffusion paths. The dissertation aims to identify recurring patterns of urban innovation processes and to make them systematically representable as a model language (Braun, 2024). This would be followed by a scientific examination of how innovation diffusion takes place in cities at different levels: within individual neighborhoods, between urban organizations, between municipalities, and in interaction with national and transnational political regimes. The multi-level perspective of transformation research offers a suitable frame of reference for this, because it describes transitions as an interplay of niches, regimes and overarching landscape developments (Geels, 2005). Such a perspective could show that urban innovations arise neither from local creativity nor exclusively from exogenous control impulses, but from the interaction of different levels, time rhythms and institutional opportunity structures. For the scientific addition, it would therefore be necessary to examine the extent to which the pattern language developed by Braun can also be used as an analytical instrument for the description of multi-stage diffusion processes.

A third topic area is the reflection of the epistemic and methodological scope of the pattern language approach itself. Braun builds on the tradition of pattern language, which goes back to Christopher Alexander and aims to make complex bodies of experience accessible in a structured and communicable form (Alexander et al., 2013). This is precisely where significant added value lies for urban innovation contexts, in which heterogeneous stakeholder groups from science, administration, business and civil society must work together. However, the question of whether patterns are primarily descriptive condensations of successful practice, heuristic figures of thought or normative design offers would have to be scientifically pursued. This distinction is not trivial, because the transfer of patterns to new urban contexts always carries the risk of underestimating historically and institutionally specific conditions. Recent work on the formal development of urban pattern language approaches therefore emphasizes that patterns only remain viable if they are thought of in a context-sensitive, relational, and multi-scale way (Salingaros et al., 2025). For the system, it would therefore make sense to explain the pattern language not as a static repertoire, but as a reflexive and adaptive knowledge format.

A fourth topic area concerns the governance dimension of urban innovation diffusion (Vrabie, 2026). The review already suggests that the dissertation understands cities as open innovation systems in which different groups of actors cooperate and need to be coordinated (Braun, 2024). The question of how governance structures enable or limit the emergence, stabilization and dissemination of urban innovations should be examined in greater depth. Studies on urban sustainability transitions show that urban transformation processes are significantly shaped by multi-level governance, i.e. by the interaction of municipal, regional, national and supranational levels (Hodson & Marvin, 2010). In this context, the role of public administrations as active intermediaries, facilitators and

translators between technical possibilities, political objectives and social acceptance should be examined. Especially in the smart city context, it becomes clear that innovation should not only generate efficiency gains, but also touch on questions of democratic legitimacy, transparency and orientation towards the common good (IEEE Technology and Society, 2026). A scientific supplement should therefore integrate governance-theoretical categories more strongly and explicitly elaborate on the role of institutional arrangements.

A fifth topic area is the greater consideration of participatory and human-centered perspectives. The present review acknowledges the systemic breadth of the dissertation and its relevance for different groups of actors (Braun, 2024). Nevertheless, it could also be investigated in what way citizens, local initiatives or intermediary organisations are involved in diffusion processes. Research on human-centered urban development highlights that urban innovation processes become successful not only through technological implementation, but through social embeddedness, participation, and collective learning processes (Participatory Design of People-Centered Cities, 2020; Basu, 2025). It follows that a model language for innovation diffusion should not only capture the logic of institutional or technical systems, but also the perspective of use, acceptance, and co-creation. For the scientific community, it would therefore make sense to explicitly describe urban innovation as a co-productive process in which legitimacy and impact are closely related.

A sixth topic area concerns the question of operationalization and practical implementation. The review makes it clear that the dissertation is methodologically sound, but at the same time remains conceptual in parts and could gain further impact through additional case studies or implementation examples (Braun, 2024). This is precisely where a particularly productive field for scientific additions lies. It would be necessary to clarify how the developed pattern language can be translated into real planning, administration or transformation processes (Schachtner/Baumann, 2024). Applications in the areas of digital administration, urban mobility, energy infrastructures, climate-oriented urban development or data-based control would be conceivable. The scientific relevance lies in bridging the gap between analytical modelling and action-based implementation. Patterns would then not only be instruments of description, but also tools of reflection, prioritization and design. Such a perspective would make the work particularly compatible with municipal practice, real-world laboratories and transfer-oriented research.

A seventh thematic area should develop the distinction and intertwining of technological and social innovation more systematically. Braun already uses a broad concept of innovation that integrates technical and social elements (Braun, 2024). Scientifically, however, it could be shown more precisely that urban innovations usually only unfold their effect in the interaction of technology, organization and social practice. Smart city solutions, for example, will have few consequences if they are not supported by suitable administrative processes, acceptance structures and learning mechanisms. This points to the character of urban systems as socio-technical configurations in which technical artifacts, institutional rules, and cultural patterns of interpretation are inextricably linked (Geels, 2005; IEEE Technology and Society, 2026). An in-depth scientific analysis of this relationship would significantly increase the analytical differentiation capacity of the plant.

3. Results

Finally, as an eighth thematic area, the normative dimension of urban innovation diffusion should be emphasized more strongly. The dissertation is designed to be technology-independent and aims to improve the structuring and communication of complex innovation processes (Braun, 2024). However, this directly raises the question of what criteria should be used to evaluate successful or desirable innovations in cities at all. In current smart city and transformation research, standards such as sustainability, resilience, inclusion, data protection, fairness and public value creation are increasingly being used for this purpose (Participatory Design of People-Centered Cities, 2020; IEEE Technology and Society, 2026). For a scientific addition, it would therefore make sense to discuss the pattern language not only as a functional control instrument, but also as a potentially normatively framed instrument of urban design. This would make it clear that innovation diffusion in cities is always associated with conflicting goals, setting priorities and political decisions.

Overall, it can be said that Steffen Braun's dissertation provides an extraordinarily viable theoretical and methodological framework for the analysis of urban innovation diffusion (Braun, 2024). This is precisely why it opens up numerous scientific connections. The in-depth conceptualization of the concept of innovation, the embedding in transition theories, the governance-oriented perspective, the participatory extension, the question of operationalization, and the greater consideration of normative evaluation standards appear to be particularly far-reaching (Geels, 2005; Hodson & Marvin, 2010; Participatory Design of People-Centered Cities, 2020). A corresponding addition to the annex would not only deepen the scientific classification of the dissertation, but also visibly increase its relevance for municipal practice, research transfer and interdisciplinary debates.

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